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Recently various sports footwear companies have produced different types of minimalist running shoes to mimic barefoot walking or running such as Vibram FiveFingers and Nike Free Run shoes. The purpose of this study was to examine the range of dorsiflexion and plantarflexion movements at the foot in barefoot conditions in comparison to Vibram FiveFingers and Nike Free Run minimalist shoes to evaluate if the minimalist footwear would affect ankle joint motion on both flat and inclined surfaces. Five elite female runners were chosen to run on a treadmill for 30s at the speed of 3 m/s on an incline of 0%, 4%, and 8%. Reflective markers were placed on the shoulder, hip, knee, ankle, and toe. Joint angles during heel strike, mid support, and toe off were then calculated and compared to determine the degree of dorsiflexion and plantarflexion movements while running at various inclines. A standard two-dimensional kinematic analysis was then conducted for foot dorsiflexion and plantarflexion angles at the heel strike, mid support and toe off for each type of footwear in each incline angle. A two-way (3 types of footwear x 3 treadmill angles) repeated measures ANOVA test was conducted at $\alpha = 0.05$ with Bonferroni adjustment if a significance was found. No statistical significant differences were found between the various types of footwear on three different inclines. These findings indicate that similar ankle joint movements were observed during the 0%, 4%, and 8% inclinations. Barefoot, FiveFingers and Free Run running shoes provide similar joint mobility during heel strike, mid support, and toe off; therefore, they all mimic barefoot running in the ankle joint.

Running shoes have recently been designed to mimic barefoot walking or running, and they are marketed with promises that runners will benefit from the effects of barefoot running. Researchers argue that barefoot running allows the body to optimize shock absorption through natural foot motions (Paquette, Baumgartner, & Songning, 2010). Little research has been completed to identify if these shoes actually enable one to perform better or if they hinder performance. Studying gait analysis with particular running shoes is extremely important because the ankle and foot serve as the foundation of structural balance, support, and propulsion (Utz-Meagher, Nulty & Holt, 2011). Gait is the pattern of movement in animals or humans of the limbs. Running gait is characterized by the fact that at some point, both feet are simultaneously in the air (Swelin-Worobec, 2012). Without an understanding of the basic human movements of both walking and running, the purpose of running shoes cannot be determined.

The gait cycle is the time period between heel strike to heel strike of the same foot (Malanga & DeLisa, 1998). The phases of human gait include the stance phase and the swing phase. The stance phase accounts for 60% of the human gait cycle, and it is generally categorized by the time period when the foot is in contact with the ground (Malanga & DeLisa, 1998). The stance phase in human gait starts from the initial contact of the foot with the ground until the last part of the foot leaves the ground. Generally, it is the time when the forefoot/heel strikes the ground until the toe leaves the ground. The swing phase accounts for the remaining 40% of the human gait cycle, and it is defined as the period of time when the foot is not in contact with the ground (Malanga & DeLisa, 1998). The stance phase can be divided into sub-phases which include forefoot/heel strike, foot flat, mid support, heel off, and toe off. Forefoot/heel strike is the initial contact of the forefoot/heel with the ground. Foot flat is the time frame when the full foot contacts the ground. Mid-support is defined as the body weight being directly over the supporting leg; heel off is the period when the heel lifts off the ground. Finally, toe off is the last remaining contact of the foot being removed from the ground (Swelin-Worobec, 2012). The stance phase is important to research in biomechanics as it comprises the majority of the gait cycle, as well as it is the only time period in which the foot contacts the ground (Levangie & Norkin, 2001). Thus, the purpose of this research study focused on the stance phase of the gait cycle.

Knowledge of the mechanics of running on an incline is important as it examines adaptive gait control mechanisms the body endures while on a slope (Telhan, Franz, Dicharry, Wilder, Riley, & Kerrigan, 2010). Studying sloped running also allows researchers to examine the changes in mechanics of the lower extremity and possibly determine causes of injuries. Sloped running is important in modern society because uphill and downhill gradients are common to competitive races such as cross-country competitions and marathons (Padulo, Annino, Migliaccio, D'Ottavio, & Tihanyi, 2012). If research allows runners to understand how slope affects running mechanics, an athlete may be able to improve their overall performance.

Vibram FiveFingers and Nike Free Run running shoes are significant to the biomechanics of running because they allow the body to imitate barefoot running, while still providing protection from the elements. Vibram FiveFingers shoe is unique because it provides very minimal cushioning and allows individual toe separation, which may improve balance and stability. These characteristics enable FiveFingers to better simulate barefoot running motion due to the likeness of the bare foot. Nike Free Run shoe, one of the most popular minimalist shoes, is flexible and lightweight and yet provides cushioning. Thus, these two types of shoes have their unique features and are the interest of this research study. There has been limited research evaluating how effective the FiveFingers and Free Run shoes are on the treadmill at 0%, 4%, and 8% incline. Cross country runners often run on different slopes in their training and competitions, so it is important to evaluate if these shoes can provide the same benefits for an inclined surface.

FiveFingers and Free Run shoes can be described as minimalist running shoes, and researchers argue that they decrease the risk of running injuries as compared to traditional running shoes (American Council on Exercise, 2011). These barefoot running shoes allow the runner to land on the balls of their feet which in turn generates less impact. The objective of the FiveFingers and Free Run shoes is to stimulate a forefoot striking pattern using the feeling of being barefoot yet still providing protection of a shoe. The way that the athlete runs, however, is dependent on their own running patterns, and it is questionable if all athletes will switch to this forefoot running pattern. Those who do switch to a forefoot strike style show greater plantarflexion, which helps performance by absorbing the impact forces of running (American Council on Exercise, 2011). This study demonstrated that the FiveFingers shoes allowed greater plantarflexion on a flat 20-metre surface, but it does not provide any insight on if the FiveFingers shoes would allow runners to have the same performance on the inclined surface.

If the research is able to show these shoes can provide a greater degree of dorsiflexion and plantarflexion while running at an incline, the changes in angles can be compared to barefoot conditions. Having a comparison will allow us to conclude if FiveFingers and Free Run shoes are an appropriate choice of footwear for inclined running. Therefore, the purpose of this current study was to investigate the angles of dorsiflexion and plantarflexion while running on the treadmill at respective degrees of incline.

Methods

Five female elite runners of the ages 20 ± 1 years of age, 1.73 ± 0.03 m in height, and 58.29 ± 3.4 kg in weight were recruited to participate in the study. Participants were recruited based on having more than 5 years of running experience and a heel strike running pattern. Institutional research ethics review was approved, and written informed consent was obtained from each participant prior to the study. The participants were fully briefed on what the study would require from them.

All participants arrived at the Exercise Physiology Laboratory. Each participant was allowed to warm up for approximately ten minutes with their regular warm-up routine on a suspended track. After warm-up, each participant was given a chance to warm up in each type of footwear, allowing the participant

to become familiar with the respective footwear. This process enabled participants to feel comfortable with their shoes. Five joint reflective markers were placed on the right side of the body at the shoulder (glenohumeral joint), hip (greater trochanter), knee (lateral epicondyle of the femur), ankle (lateral malleolus of fibula), and toe (base of fifth metatarsal). Each participant wore tight fitting black running clothes to provide better contrast for video analysis and minimize marker movements.

During the testing each participant ran 30 seconds at the speed of 3 m/s on each incline treadmill angle of 0%, 4%, and 8% for the FiveFingers shoe, Free Run shoe, and barefoot condition. The running speed of 3 m/s was selected due to its prevalence in a similar running research study, which allowed for a comparison between both studies (Telhan et al., 2010). Participants had three minutes to rest between each incline treadmill angle and five minutes to rest between each type of footwear, so the influence of the fatigue was minimized in this study. The order of footwear and barefoot conditions and incline angles were randomized to reduce any order effect. Data collection was concluded in one day for an hour in duration per subject.

A JVC (Model: GR-D371V) video camera was positioned to capture the sagittal view of running motion at 60Hz with a 650W artificial light directed toward the participant. A standard two-dimensional kinematic analysis was conducted for foot dorsiflexion and plantarflexion angles at the heel strike, mid support, and toe off for each type of footwear in each incline angle. All video trials were then transferred onto a University computer in the Biomechanics Lab for gait analysis. Digital filter was applied at 5 Hz to filter the data. A two-way (3 types of footwear x 3 treadmill angles) repeated measures ANOVA test was conducted at $\alpha = 0.05$ and followed by post-hoc t-test with Bonferroni adjustment if a significant difference was found. All statistical analyses were conducted with SPSS (version 18) software.

Results

To conclude this research study, SPSS software was used to compare different types of footwear on similar inclines. At a 0%, 4% and 8% incline the foot angles between Barefoot, Vibram, and Nike conditions were compared during the heel strike phase, Table 1.

Similarly at a 0%, 4%, and 8% incline the foot angles between Barefoot, Vibram, and Nike conditions were compared during the mid support phase, Table 2.

Lastly, at a 0%, 4%, and 8% incline the foot angles between Barefoot, Vibram, and Nike conditions were compared during the toe off phase, Table 3.

In the heel strike phase, the barefoot condition showed the greatest angle on a 0% and 4% incline (106.8° ± 11.4° and 104.2° ± 6.4°), but Nike showed the greatest angle on an 8% incline (103.0° ± 4.9°), Table 1. In the mid support phase,

Table 1. Descriptive statistics between different incline angles and types of footwear during the heel strike phase. Data are means (SD).

Incline	0%	4%	8%
Barefoot	106.8°	104.2°	102.2°
	(11.4°)	(6.4°)	(4.9°)
Vibram	100.7°	100.8°	101.5°
	(3.6°)	(8.6°)	(10.0°)
Nike	104.3°	101.0°	103.0°
	(11.1°)	(3.5°)	(4.9°)

Table 2. Descriptive statistics between different incline angles and types of footwear during the mid support phase. Data are means (SD).

Incline	0%	4%	8%
Barefoot	83.1°	81.0°	80.6°
	(3.7°)	(4.1°)	(3.8°)
Vibram	81.1°	79.8°	77.9°
	(6.0°)	(4.0°)	(6.2°)
Nike	86.0°	86.3°	85.1°
	(2.5°)	(4.4°)	(3.3°)

Table 3. Descriptive statistics between different incline angles and types of footwear during the toe off phase. Data are means (SD).

Incline	0%	4%	8%
Barefoot	128.4°	127.1°	128.2°
	(4.9°)	(5.5°)	(4.8°)
Vibram	124.5°	126.5°	125.3°
	(5.2°)	(2.1°)	(4.5°)
Nike	130.8°	131.8°	132.4°
	(6.4°)	(6.2°)	(5.6°)

Nike showed the largest angle in all three inclines on the treadmill (86.0° ± 2.5° , 86.3° ± 4.4° , and 85.1° ± 3.3°), Table 2. In the toe off phase, Nike also showed the largest angle on all three inclines on the treadmill (130.8° ± 6.4° , 131.8° ± 6.2°, and 132.4° ± 5.6°), Table 3. Vibram demonstrated the smallest angle in all three phases of the gait cycle on all inclines, Table 1, Table 2, and Table 3.

While there were no significant differences found in the study, some of the comparisons did approach significance. When the Vibram shoe was compared with the barefoot condition at 4% incline during the heel strike, it showed a large difference in the ankle movement (100.8° ± 8.6° vs. 104.2° ± 6.4°), but it was not statistically significant at $p < 0.042$, Table 4.

Table 4. Statistical probability comparisons between different types of footwear in each incline angle at the heel strike.

Incline	0%	4%	8%
Barefoot vs. Vibram	0.184	0.042	0.821
Barefoot vs. Nike	0.302	0.222	0.526
Vibram vs. Nike	0.412	0.958	0.695

*Statistical significance at p < 0.006 with Bonferroni adjustment

In addition, when Nike was compared with barefoot condition during the mid support phase, the statistical probability results showed a gradual approach to significance from incline angle of 0% ($p < 0.166$) to 8% ($p < 0.007$), Table 5.

Table 5. Statistical probability comparisons between different types of footwear in each incline angle at the mid support phase.

Incline	0%	4%	8%
Barefoot vs. Vibram	0.395	0.445	0.171
Barefoot vs. Nike	0.166	0.013	0.007
Vibram vs. Nike	0.185	0.058	0.026

*Statistical significance at p < 0.006 with Bonferroni adjustment

Further, when both shoes were compared to one another during the toe off, Vibram and Nike showed an approach to statistical significance at $p < 0.071$, Table 6.

Table 6. Statistical probability comparisons between different types of footwear in each incline angle at the toe off.

Incline	0%	4%	8%
Barefoot vs. Vibram	0.268	0.810	0.453
Barefoot vs. Nike	0.194	0.191	0.083
Vibram vs. Nike	0.165	0.129	0.071

*Statistical significance at p < 0.006 with Bonferroni adjustment

There were no statistically significant differences found when analyzed with SPSS software. Because both types of minimalist footwear are constructed with similar materials and display lightweight characteristics, the slight differences in their construction had no impact on ankle joint motion. Both types of minimalist shoes allow the ankle joint to move unrestricted.

Discussion

The purpose of this study was to examine the range of dorsiflexion and plantarflexion movements at the foot joint in barefoot conditions in comparison to Vibram FiveFingers and Nike Free Run minimalist shoes to evaluate if these minimalist footwear types would affect ankle joint motion on the flat condition or on an incline. According to Rothschild (2012) barefoot runners are able to change from a rearfoot heel striking pattern to a forefoot or midfoot striking pattern because of an increased plantarflexion range of motion through the ankle joint. When transitioning from shod to barefoot, there was no increase in plantarflexion range of motion in the ankle joint seen in the five female elite runners in this research study. Rothschild (2012) also noted there was an overall greater joint movement through the ankle joint in the barefoot condition. During this study, there was no statistically significant difference in the ankle joint between shod and unshod. Some possible reasons why there was no difference between shod and unshod in the ankle joint while running is because minimalist shoes were worn, and it is possible Rothschild (2012) had used traditional running shoes. The agreeable points between this study and the research of Rothschild (2012) are that minimalist shoes are a good transition from running shod to running barefoot, as minimalist shoes effectively mimic barefoot conditions.

Although there is little research completed on barefoot and minimalist shoe running on an incline, there are some studies that investigated barefoot running on flat condition. According to Utz-Meagher et al. (2011) there was a significant change in the foot angle while running barefoot. It was noted that the ankle joint angles were significantly decreased when the par-

ticipants ran barefoot. The decrease in the ankle joint range of motion allowed the participants to change to a midfoot or forefoot strike (Utz-Meagher et al., 2011). There was no change in striking pattern or a decrease in foot angle when the five female elite runners were studied. Although a significant decrease in foot angle was observed, Utz-Meagher et al. (2011) only tested participants on a flat surface, and it is unknown what type of footwear they were using as a comparison. In this study no statistically significant increase or decrease in foot angle was seen on a flat condition, 4% incline, or 8% incline in the Nike Free Run or Vibram FiveFingers. However, the author recognizes this research study had a small sample size, yet it provides an important preliminary understanding in the evolution of gait.

Conclusion

The results of this research study conclude that minimalist running shoes do in fact mimic barefoot running. A similar range of motion at the ankle joint between footwear conditions was seen throughout all types of footwear in all three phases of running gait. These similar ranges of motion were also similar with different incline levels on the treadmill. Overall, when five female elite runners performed in Vibram FiveFingers shoes, Nike Free Run shoes, and barefoot there was a similar range of motion in the ankle joint while running. These types of footwear did not hinder the performance in the ankle joint while running; therefore, any of these shoes would be an appropriate choice when looking to select footwear for inclined treadmill running. It is important to note that only the joint angle was examined while there are many conditions that affect performance. Further research is needed to evaluate other factors such as angular velocity, acceleration, force and torque. From the results of this study, the author suggests that all three types of footwear both do not hinder one's range of motion in the ankle joint while running. Future studies are warranted to study the kinetic chain of joints that are linked while running, such as the hip and knee joints. Also, it would be critical to examine the pronation and supination of the ankle joint movement with these types of footwear. These studies will provide a comprehensive understanding about barefoot running and minimalist shoes.

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